(19) Japan Patent Office (JP)
(12) Publication of Patent Applications (A)
(11) Japanese Patent Application Kokai Publication Number: Kokai No. 11-176727
(43) Kokai Publication Date: July 2, 1999

(51) Int.Cl.[6]	Domestic Classification Symbol	F I	
H01L 21/027		H01L 21/30	526Z
G01B 17/00		G01B 17/00	B
G03F 7/20	521	G03F 7/20	521
		H01L 21/30	514C

Request for Examination: Not yet requested. The Number of Claims: 5. (6 pages total)

(21) Application Filing Number: Patent Application No. 9-341445
(22) Application Filing Date: December 11, 1997
(71) Applicant: 000004112
Nikon Corporation
3-2-3 Marunouchi, Chiyoda-ku, Tokyo
(72) Inventor: Naomasa SHIRAISHI
Nikon Corporation
3-2-3 Marunouchi, Chiyoda-ku, Tokyo
(74) Representative: Satoshi ŌMORI, Patent Attorney

(54) [Title of the Invention] PROJECTION EXPLOSION or EXPOSURE APPARATUS

(57) [Summary]

[Problem] The wavelength of an exposure light is made shorter in effect, and even in the case where the exposure is performed in a liquid, a position of the surface of a substrate along a light axis of a projection optical system is detected with high accuracy.

[Means for Solving Problem] Liquid 7 is supplied inside side wall 8 so that the space between lens 4 of the projection optical system which is located nearest to wafer W and wafer W is filled with the liquid. Ultrasonic waves are emitted from ultrasonic wave emitting system 5, and the ultrasonic waves reflected at ultrasonic wave focusing point SS are received by ultrasonic wave receiving system 6. Based on the detection signals from ultrasonic wave receiving system 6, the defocus amount from the best focus position at ultrasonic wave focusing point SS is determined. Based on the determined defocus amount, sample table 9 is driven in the Z-direction to control the focus position.

【SCOPE OF CLAIMS】

【Claim 1】 A projection explosion apparatus for transferring a pattern of a mask through a projection optical system onto a substrate, said projection explosion apparatus characterized to comprise a liquid immersion device which supplies predetermined liquid on a surface of the substrate and an ultrasonic type surface position detection device which detects a position of the surface along a light axis of the projection optical system by detecting ultrasonic waves which are transmitted to the surface of the substrate through the liquid and are reflected at the surface of the substrate.

【Claim 2】 A projection explosion apparatus according to claim 1, characterized in that when a photosensitive material is applied to the surface of said substrate, said surface position detection device detects the position of the surface of said photosensitive material along the light axis of said projection optical system.

【Claim 3】 A projection explosion apparatus according to claim 1 or 2, characterized in that said liquid is supplied so that the space between the end portion of an optical element of said projection optical system on the side of said substrate and the surface of said substrate is filled with said liquid.

【Claim 4】 A projection explosion apparatus according to claim 1, 2, or 3, characterized in that said liquid is water or organic solvent.

【Claim 5】 A projection explosion apparatus according to any one of claims 1-4, characterized in that it is provided with a substrate stage that while holding said substrate, positions said substrate in a plane perpendicular to the light axis of said projection optical system and with a height control stage that based on detection results from said surface position detection device, controls the position of said substrate along the light axis of said projection optical system.

【Detailed Description of the Invention】

【0001】

【Field of Industrial Application】 The present invention relates to a projection explosion or exposure apparatus used for the lithography process for manufacturing, e.g., semiconductor devices, liquid crystal devices, or thin film magnetic heads.

【0002】

【Prior Art】 When manufacturing semiconductor devices, etc., there are used projection explosion apparatuses of, e.g., stepper type or step-and-scan type which transfer, via a projection optical system, an image of a pattern of a reticle, as a photomask, onto each shot area on a wafer (or a glass plate, etc.), as a substrate, to which resist is applied.

【0003】 The resolution of the projection optical system provided in such a projection explosion apparatus becomes higher as the exposure wavelength used is made shorter and, also, as the numerical aperture of the projection optical system is made larger. For this reason, along with the miniaturization of integrated circuits, the exposure wavelength used for the projection explosion apparatus is becoming shorter and shorter year by year, and the numerical aperture of the projection optical system is also becoming larger and larger. In this context, the presently dominant exposure wavelength is 248 nm from a KrF excimer laser, but the use of a still shorter wavelength of 193 nm from an ArF excimer laser is now being considered.

【0004】 In addition, when performing exposure, the depth of focus (DOF) is an important factor along with the resolution. The resolution R and the depth of focus δ are respectively expressed by the following formulas:

$$R=k_1\cdot\lambda/NA, \qquad (1)$$
$$\delta=k_2\cdot\lambda/NA^2, \qquad (2)$$

where λ is the exposure wavelength, NA is the numerical aperture of the projection optical system, and k_1 and k_2 are process coefficients. Assuming the case where an identical resolution is obtained, a larger depth of focus can be obtained as an exposure light of a shorter wavelength is used. However, when considering the spectral transmittance characteristics of transmitting optical members (glass materials) used for projection optical systems, there are at the

present time scarcely any glass materials through which an exposure light having a wavelength shorter than 193 nm of an ArF excimer laser can transmit and which can at the same time form a relatively large lens.

【0005】

【Problem to Be Solved by the Invention】 As described above, with respect to the conventional projection explosion apparatuses (projection optical systems), it is difficult to use an exposure light having a wavelength shorter than 193 nm of an ArF excimer laser. To address this problem, the liquid immersion method has been proposed as a method to make the exposure wavelength shorter in effect. This is designed to, by immersing a wafer in a predetermined liquid and thus by taking advantage of the fact that the wavelength of the exposure light in the liquid becomes 1/n times (n is the refractive index of the liquid and is generally about 1.2 to 1.6) of that in the air, improve the resolution and increase the depth of focus.

【0006】 By the way, since it is required that during exposure, the entirety of the exposure region be within the range of the depth of focus of the projection optical system, a focusing mechanism (autofocus mechanism) is provided in the projection explosion apparatus. This mechanism is generally configured such that a light beam is incident with an oblique incidence angle on the surface of a wafer to be exposed, the reflected light thereof is received by an opposite optical system to detect the focus condition of the wafer surface, and by moving the wafer vertically to adjust it to the focus position.

【0007】 A photosensitive film (photoresist) is applied to the wafer surface to be exposed, and onto this photoresist is transferred the pattern. It is therefore preferable that the photoresist surface is made coincide with the focus position of the projection optical system, and thus it is required that the position of the photoresist surface be detected. In the conventional projection explosion apparatuses, the space where the wafer is placed is filled with a gas, e.g., air or nitrogen. In this regard, for example, the refractive index of air is 1, and the refractive index of the photoresist applied to the wafer surface is approximately 1.7. Thus, the light reflectance at the air/photoresist interface can be calculated by the Fresnel equations as follows:

$$\begin{aligned}\text{Reflectance} &= \{(1-1.7)/(1+1.7)\}^2 \times 100 \\ &= 6.7\ (\%). \end{aligned} \tag{3}$$

A relatively large amount of the light beams for the focus detection is reflected at the air/photoresist interface, and thus the photoresist surface position can be detected.

【0008】 However, in the case of a projection explosion apparatus in which the liquid immersion method is adopted, it will be configured such that the space where a wafer is placed is filled with a liquid. In the case where the liquid is, for example, water, its refractive index is 1.3, and the light reflectance at the water/photoresist interface can be calculated by the Fresnel equations as follows:

$$\begin{aligned}\text{Reflectance} &= \{(1.3-1.7)/(1.3+1.7)\}^2 \times 100 \\ &= 1.8\ (\%). \end{aligned} \tag{4}$$

Since compared with the air/photoresist interface, the differential between the refractive index of the space and that of the photoresist becomes significantly small at the water/photoresist interface, the reflectance of the light beams for the focus detection decreases, which makes it difficult to precisely detect the photoresist surface position.

【0009】 In consideration of such situations, an object of the present invention is to provide a projection explosion or exposure apparatus in which the wavelength of the exposure light is made smaller in effect and which can transfer even finer patterns. Further, it is also an object to provide a projection explosion apparatus that even in the case where exposure is performed on a substrate over which a photosensitive material is applied, can detect with high accuracy the position of

the surface of the photosensitive material along the light axis of the projection optical system.

【0010】

【Means for Solving the Problems】 A projection explosion apparatus of the present invention is a projection explosion apparatus for transferring a pattern of a mask (R) through a projection optical system (PL) onto a substrate (W), the projection explosion apparatus characterized to comprise a liquid immersion device (2, 8) which supplies predetermined liquid (7) on a surface of the substrate (W) and an ultrasonic type surface position detection device (5, 6) which detects a position of the surface along a light axis of the projection optical system (PL) by detecting ultrasonic waves which are transmitted to the surface of the substrate through the liquid (7) and are reflected at the surface of the substrate.

【0011】 In accordance with such projection explosion apparatus of the present invention, since the pattern of the mask (R) is exposed onto the surface of the substrate (W) via the liquid (7), the wavelength of the exposure light at the surface of the substrate can be made smaller in effect, with the wavelength becoming 1/n times (n is the refractive index of the liquid (7)) of that in the air. Further, since the position of the surface of the substrate (W) along the light axis is detected with high accuracy by the ultrasonic type surface position detection device (5, 6), the position can be detected with high accuracy even in liquid (7) in which it is difficult to detect the surface position by an optical type surface position detection device.

【0012】 Further, it is preferable that when a photosensitive material (PR) is applied to the surface of the substrate (W), the surface position detection device (5, 6) detects the position of the surface of the photosensitive material (PR) along the light axis of the projection optical system (3, 4). In this case, the image surface of the projection optical system (3, 4) can be adjusted to the surface of the photosensitive material (PR). Further, it is preferable that the liquid (7) is supplied so that the space between the end portion of an optical element (4) of the projection optical system (PL) on the side of the substrate (W) and the surface of the substrate (W) is filled with the liquid. In this case, the wavelength of the exposure light at the surface of the substrate (W) can be made smaller in effect, with the wavelength becoming 1/n times (n is the refractive index of the liquid (7)) of that in the air. Further, since the lens barrel (3) of the projection optical system (PL) does not come into contact with the liquid (7), there is the advantage that the lens barrel (3) of the projection optical system (PL) becomes unlikely to be corroded.

【0013】 Further, the liquid (7) is water (having a refractive index of 1.3) or organic solvent (e.g., alcohol (e.g., ethanol (having a refractive index of 1.36) or cedar oil (having a refractive index of 1.52)). In this case, when water is used as the liquid (7), there is the advantage that it is easily available. Further, when organic solvent is used as the liquid (7), there is the advantage that the lens barrel (3) of the projection optical system (PL) becomes unlikely to be corroded. Still further, when cedar oil is used as the liquid (7), it has a large refractive index of about 1.5, and thus the wavelength of the exposure light can be made still smaller in effect.

【0014】 Further, it is preferable that the projection explosion apparatus is provided with a substrate stage (10) that while holding the substrate (W), positions the substrate (W) in a plane perpendicular to the light axis of the projection optical system (PL) and with a height control stage (9) that based on detection results from the surface position detection device (5, 6), controls the position of the substrate (W) along the light axis (3, 4) of the projection optical system. In this case, the surface of the substrate (W) can be adjusted with high accuracy relative to the image surface of the projection optical system (3, 4).

【0015】

【Embodiment of the Invention】 In the following, an embodiment of the present invention will be described referring to FIGS. 1-3. FIG. 1(a) shows an outline configuration of the projection explosion or exposure apparatus of the embodiment; in FIG. 1(a), illumination light IL constituted by ultraviolet pulse

light of 193 nm wavelength emitted from illumination optical system 1 including an ArF excimer laser as the exposure light source, an optical integrator, a field stop, a condenser lens, etc. illuminates a pattern provided on reticle R. The pattern of reticle R is, via projection optical system PL that is telecentric on both sides (or one-side telecentric on the wafer side), reduction projected with projection magnification β (β being, e.g., 1/4 or 1/5) onto an exposure area on the wafer W on which photoresist PR is applied. It is to be noted that as illumination light IL, KrF excimer laser light (248 nm wavelength), F_2 excimer laser light (157 nm wavelength), the i-line of a mercury lamp, etc. may be used. In the following, description will be made by setting the Z-axis parallel to light axis AX of projection optical system PL and by, in a plane perpendicular to the Z-axis direction, setting the Y-axis along the direction perpendicular to the plane of the drawing of FIG. 1(a) and setting the X-axis along the direction parallel to the plane of the drawing.

【0016】 Reticle R is held on reticle stage RST; in reticle stage RST is incorporated a mechanism that can finely move in the X-direction, the Y-direction, and the rotational direction. The two-dimensional position and rotation angle of reticle stage RST are being measured in real time by a laser interferometer (not shown). On the other hand, wafer W is held, via a wafer holder (not shown), on sample table 9; sample table 9 is fixed on Z-stage 10 that controls the focus position (the position in the Z-direction) and inclination angle of wafer W. On sample table 9 is provided a cylinder-shaped side wall 8, and the inside thereof is filled with liquid 7. Liquid 7 is, by liquid supply/recovery system 2 constituted by a pump, etc., supplied to the inside of side wall 8 before an exposure process and recovered after the exposure process, via nozzle 2a. It should be noted that in the projection explosion apparatus of the embodiment, water (having a refractive index of 1.3) is used as liquid 7, and the wavelength of the light in the water becomes 1/1.3 times of that in the air, so that the wavelength of the exposure light from the ArF excimer laser is made shorter in effect, i.e., to be approximately 148 nm.

【0017】 Further, lens barrel 3 of projection optical system PL is made of metal, and to prevent the lens barrel from being corroded by liquid 7, the contact portion of projection optical system PL with liquid 7 is restricted exclusively to lens 4 located nearest to wafer W. Further, on the side surface of lens barrel 3 of projection optical system PL is attached a focus position detection system (hereinafter, referred to as "AF sensor 5, 6") constituted by ultrasonic wave emitting system 5 and ultrasonic wave receiving system 6.

【0018】 FIG. 1(b) is an enlarged view illustrating side wall 8 and its vicinity of FIG. 1(a); in FIG. 1(b), to side wall 8 is provided an openable-closable door 8a that is used when wafer W is conveyed on sample table 9 or is carried out of sample table 9. Further, nozzle 2a of liquid supply/recovery system 2 is configured such that it can be vertically driven when the liquid is supplied or recovered.

【0019】 Returning to FIG. 1(a), Z-stage 10 is fixed on XY-stage 11 that moves along the XY-plane that is parallel to the image surface of projection optical system PL, and XY-stage 11 is mounted on a base, not shown. By controlling the focus position (the position in the Z-direction) and inclination angle of wafer W, Z-stage 10 adjusts the surface of photoresist PR on wafer W to the image surface of projection optical system PL by means of an autofocus system and an autoleveling system; XY-stage 11 performs the positioning of wafer W in the X- and Y-directions. The two-dimensional position and rotation angle of sample table 9 (w) are being measured as the position of moving mirror 12 in real time by laser interferometer 13. With based on the measurement results, control information being sent from main control system 14 to wafer stage drive system 15, the operations of Z-stage 10 and XY-stage 11 are controlled; when exposure is to be performed, each of the shot areas on wafer W sequentially moves to the exposure position, and the pattern of reticle R is exposure-transferred to each shot area.

【0020】 Next, the AF sensor 5, 6 of the embodiment will be described. FIG. 2(a) shows in an enlarged scale the lower part of the projection optical system of the embodiment and its vicinity; in FIG. 2(a), ultrasonic wave emitting system 5 is

provided with ultrasonic wave generating device 5a and ultrasonic wave focusing device 5b. Ultrasonic waves with a frequency of about from 50 MHz to 500 MHz having been emitted from ultrasonic wave generating device 5a constituted by piezoelectric device, etc. are focused by ultrasonic wave focusing device 5b on focusing point SS on the surface of photoresist PR applied to wafer W, are reflected at focusing point SS, and enter ultrasonic wave receiving system 6. Ultrasonic wave receiving system 6 is provided with ultrasonic wave receiving device 6a, ultrasonic wave focusing device 6b, and sound insulating plate 6c that can vibrate; the ultrasonic waves having entered ultrasonic wave receiving system 6 are focused by ultrasonic wave focusing device 6b and enter, via an opening of sound insulating plate 6c, ultrasonic wave receiving device 6a. Detection signals from ultrasonic wave receiving device 6a are supplied to main control system 14. It is to be noted that the opening, which makes ultrasonic waves pass therethrough, is provided in the center portion of sound insulating plate 6c, and main control system 14, by laterally shifting (or vibrating) sound insulating plate 6c by means of sound insulating plate drive mechanism 6d, detects the position where the detection signal of ultrasonic wave receiving device 6a becomes maximum. Alternatively, the detection signal of ultrasonic wave receiving device 6a may be synchronously detected with a signal synchronized with the signal by which sound insulating plate 6c is vibrated.

【0021】 Figure 2(b) shows the enlarged view of the vicinity of the focusing point SS of ultrasonic waves on the surface of the photoresist PR, and in this figure 2(b), the photoresist PR for photosensitization is applied on the wafer W. Even if the position SS of the surface of the photoresist PR are tried to be detected by the AF sensor of the conventional optical-type and the oblique incidence-type, the refractive index of the liquid 7 and that of the photoresist PR are almost equivalent so that the reflectance becomes extremely low. Therefore the position SS' to be detected is not placed on the surface of the photoresist PR, and the image surface of the projection optical system PL is adjusted to the surface of the substrate of the wafer W itself. The ultrasonic waves of the AF sensors 5, 6 in this example go along the pass 16 and are reflected at the surface of the photoresist PR. Therefore the position SS on the surface of the photoresist PR is detected precisely and the surface of the photoresist PR can be focused onto the image surface with high precision.

【0022】 In addition, the Z-direction position of the surface of photoresist PR is, in accordance with the principle of the AF sensor of the conventional optical-type and the oblique incidence-type, detected from the lateral shift amount of the ultrasonic wave focusing position on ultrasonic wave receiving device 6a. More specifically, since if wafer W shifts downwardly (in the Z-direction) in FIG. 2(b), then the focusing position on ultrasonic wave receiving device 6a in FIG. 2(a) shifts upwardly and since if wafer W shifts upwardly in FIG. 2(b), then the focusing position on ultrasonic wave receiving device 6a shifts downwardly, the focus position change amount of the surface of photoresist PR can be determined by the lateral shift amount. To this end, it would suffice to determine in advance the best focus position by means of, e.g., a test print and then to, at that time, make the opening center (or the vibration center) of sound insulating plate 6c coincide with the center of the ultrasonic wave focusing position.

【0023】 FIG. 3 shows, by way of an example, the relationship between focus signal D obtained by synchronously detecting the detection signal from ultrasonic wave receiving system 6 and the focus position Z of the surface of photoresist PR. In main control system 14, with the detection signals from ultrasonic wave receiving device 6a being synchronously rectified with the drive signal of sound insulating plate 6c, focus signal D that changes in approximate proportion to focus position Z in a predefined range is generated in correspondence with the ultrasonic wave focusing point SS on the surface of photoresist PR. In the embodiment, focus signal D, which corresponds to the ultrasonic wave focusing point SS, is calibrated so that it becomes zero when focusing point SS coincide with the image surface (best focus position) of projection optical system PL, and thus main control system 14 can determine the

defocus amount (shift amount) by way of focus signal D. Exposure is to be performed by moving Z-stage 10 (wafer W) downwardly when the focus position of wafer W is located above the reference position and by moving Z-stage 10 (wafer W) upwardly when the focus position of wafer W is, in contrast, located below the reference position.

【0024】 It is to be noted that while, in the embodiment, water (having a refractive index of 1.3) is used as liquid 7, organic solvent (e.g., alcohol or cedar oil) may also be used as liquid 7. In this case, there is the advantage that the lens barrel 3 of the projection optical system PL becomes unlikely to be corroded. Further, when cedar oil (having a refractive index of 1.5) is used, it has a large refractive index of about 1.5, and thus the wavelength of the exposure light can be made still smaller in effect.

【0025】 In addition, with respect to the focus position detection, it may also be configured such that by disposing a sound insulating plate having a plurality of openings in ultrasonic wave emitting system 5, each of the focus positions at a plurality of points on the photoresist surface is detected or such that by disposing a sound insulating plate having a large opening in ultrasonic wave emitting system 5 and by, at the same time, disposing a sound insulating plate having a plurality of openings in ultrasonic wave receiving system 6, each of the focus positions at a plurality of points is similarly detected.

【0026】 Further, while, in the above-described embodiment, the focus position of the surface of the photoresist of the wafer is detected by using ultrasonic waves, a leveling sensor that detects the inclination angle of the surface of the photoresist by using ultrasonic waves may also be used. In this leveling sensor, it would suffice to irradiate ultrasonic waves that proceed almost parallel to the wafer surface and to detect the sound collecting position of the ultrasonic waves reflected.

【0027】 It should be noted that needless to say, the present invention is not limited to the above-described embodiment but can have various configurations within the scope not departing from the essence of the present invention.

【0028】

【Effect of the Invention】 In accordance with the projection explosion or exposure apparatus of the present invention, since the image of a mask pattern is exposed, via liquid, onto the surface of a substrate, the wavelength of the exposure light at the surface of the substrate can be made smaller in effect, with the wavelength becoming the inverse number-times of the refractive index of the liquid of that in the air. Further, since the position of the surface of the substrate along the light axis is detected with high accuracy by an ultrasonic type surface position detection device, the position can be detected with high accuracy even in liquid in which it is difficult to detect the surface position by an optical type surface position detection device.

【0029】 Further, in the case where the surface position detection device detects the position of the surface of a photosensitive material along the light axis of the projection optical system, the surface of the photosensitive material can be adjusted with high accuracy to the image surface of the projection optical system based on the detection information. Further, in the case where the liquid is supplied so that the space between the end portion of an optical element of the projection optical system on the side of the substrate and the surface of the substrate is filled with the liquid, the wavelength of the exposure light can be made smaller in effect, with the wavelength becoming 1/n times (n is the refractive index of the liquid) of that in the air. Further, since the lens barrel of the projection optical system does not come into contact with the liquid, there is the advantage that the lens barrel of the projection optical system becomes unlikely to be corroded.

【0030】 Further, when the liquid is water, there is the advantage that it is easily available. When the liquid is organic solvent (e.g., alcohol or cedar oil), there is the advantage that the lens barrel of the projection optical system is unlikely to be corroded. Still further, when cedar oil is used as the liquid, it has a larger refractive index of about 1.5 compared with, e.g., water (having a refractive index of 1.3), and thus the wavelength of the exposure light can be made still smaller in

effect.

【0031】 Further, in the case where the projection explosion apparatus is provided with a substrate stage that while holding the substrate, positions the substrate in a plane perpendicular to the light axis of the projection optical system and with a height control stage that based on detection results from the surface position detection device, controls the position of the substrate along the light axis of the projection optical system, the image surface of the projection optical system can be adjusted with high accuracy to the exposure position on the surface of the substrate.

【Brief Description of the Drawings】

【FIG. 1】 (a) is an outline configuration drawing showing a projection explosion apparatus embodiment example of the present invention; (b) is an enlarged view illustrating side wall 8 and its vicinity of FIG. 1(a).

【FIG. 2】 (a) is a partial enlarged view showing the configuration of the lower part of the projection explosion apparatus; (b) is an enlarged view of the B portion of FIG. 2(a).

【FIG. 3】 This is a drawing showing the relationship between the focus position Z of the surface of the photoresist on wafer W and focus signal D.

【Explanations of Letters or Numerals】

W wafer
R reticle
PL projection optical system
1 illumination optical system
2 liquid supply/recovery system
3 lens barrel
4 lens
5 ultrasonic wave emitting system
6 ultrasonic wave receiving system
7 liquid
8 side wall
9 sample table
10 Z-stage
14 main control system
15 wafer stage drive system